PossessedHand: A Hand Gesture Manipulation System using Electrical Stimuli

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ABSTRACT

Acquiring knowledge about the timing and speed of hand gestures is important to learn physical skills, such as playing musical instruments, performing arts, and making handicrafts. However, it is difficult to use devices that dynamically and mechanically control a user's hand for learning because such devices are very large, and hence, are unsuitable for daily use. In addition, since groove-type devices interfere with actions such as playing musical instruments, performing arts, and making handicrafts, users tend to avoid wearing these devices. To solve these problems, we propose PossessedHand, a device with a forearm belt, for controlling a user's hand by applying electrical stimulus to the muscles around the forearm of the user. The dimensions of PossessedHand are $10 \times 7.0 \times 8.0$ cm, and the device is portable and suited for daily use. The electrical stimuli are generated by an electronic pulse generator and transmitted from 14 electrode pads. Our experiments confirmed that PossessedHand can control the motion of 16 joints in the hand. We propose an application of this device to help a beginner learn how to play musical instruments such as the piano and koto.

Categories and Subject Descriptors

B4.2 [**Input/output and data communications**]: Input/Output Devices

General Terms

Design

Keywords

interaction device, output device, wearable, hand gesture, electrical stimuli

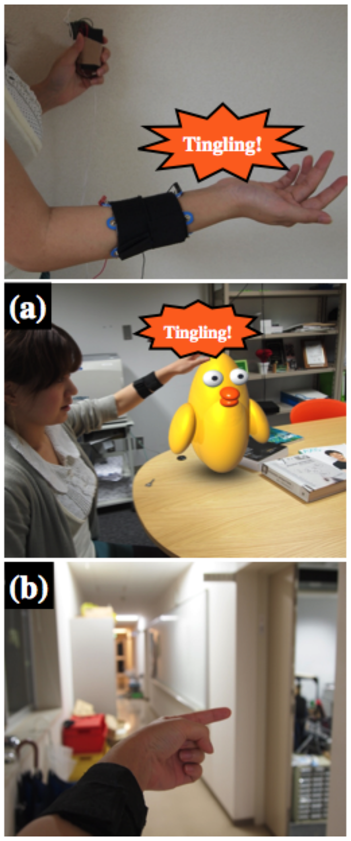

Figure 1: Interaction examples of PossessedHand. (a)A feedback system. (b)A navigation system.

1. INTRODUCTION

Although a number of input systems for hand gestures have been proposed, very few output systems have been proposed for hand gestures. If a computer system controls a user's hand, the system can also be used to provide feedbacks to various interaction systems such as systems for recognizing virtual objects (Fig. 1-a) and navigation (Fig. 1-b), assistant systems for playing musical instruments, and a substitute sensation system for the visually impaired and hearing impaired. In this paper, we propose PossessedHand, a device with a forearm belt, for controlling a user's hand by applying electrical stimulus to the muscles around the forearm.

2. PHASE OF DEVELOPMENT

There are four phases for controlling the hand posture. In this research, we confirm the phase for which PossessedHand can be used. Thereafter, we propose interaction systems based on PossessedHand.

- Phase. 1 : Although the user cannot visually confirm the hand motion, he/she feels the motion owing to his/her somatic sense.
  (e.g., Providing feedback for recognizing virtual objects)
- Phase. 2 : User can visually confirm the motion.
  (e.g., Learning systems for performing arts)
- Phase. 3 : User's fingers can be independently controlled to achieve grasping and opening motions.
  (e.g.,Assistant systems for musical performances and sport activities, navigation systems, and sensory substitution systems for the visually impaired and the hearing impaired)
- Phase. 4 : User's hand can be controlled to achieve fine motions such as pinching using the thumb and index finger.
  (e.g., Learning systems for finger languages and for making handicrafts)

Many devices that directly stimulate a user's fingers[6] are proposed. However, users tend to avoid wearing devices placed on area A, which is shown in Figure 2; this is because area A is used to touch, hold, and pinch real objects. Area A interferes with playing musical instruments, performing arts, and making handicrafts. Groove-type devices that dynamically and mechanically control a user's hand are available. Such devices can control a user's hand for the phases 1-4. However, such devices cover most of area A. Although a device that can be worn on the forearm is proposed[16], it is too large for daily use. We propose a small device that can control a user's hand and avoid covering area A.

3. RELATED WORK

Electrical muscle stimulation (EMS) has several applications. EMS is widely used in low-frequency therapeutic equipments and in devices for ergotherapy[9]. Akamatsu et al. applied EMS for performing arts[18].

Our goal is to control a user's hand by EMS, which is similar to functional electrical stimulation (FES)[8], [7],[17], [14]. In FES, electric currents are used to activate nerves innervating extremities that are affected by paralysis resulting from stroke or other neurological disorders and injuries of spinal cord or head; FES can be used to restore functions in people with disabilities[19].

Watanabe et al. and Kruijff et al. proposed a technique in which a user's wrist can be controlled with two degrees of freedom by stimulating four muscles[14], [5]. They confirmed that they could control wrist motion by electrically stimulating a muscle because such a stimulation results in the motion of the tendon connected to the wrist. However, they did not consider the motion of finger joints; this motion is important for controlling the hand posture. Moreover, they use invasive electrodes embedded under the skin; such electrodes are not suitable for daily use. For enabling daily use, we need to use noninvasive electrodes. In addition, we need to avoid placing electrodes on hands or fingers because they are used to hold or touch objects.

In this paper, we propose PossessedHand, a device used for controlling a user's hand by applying an electrical stimulus to the muscles around the forearm with noninvasive electrode pads. Muscles, which are involved in finger motions, are clustered in the forearm[10]. PossessedHand has 14 electrode pads placed on the forearm to stimulate these muscles. The tendons that are connected to the muscles move the finger joints. There are no precedent researches on the manner in which hand posture can be controlled by providing only electrical stimulation to the forearm. First, we conducted an experiment to identify which and how many finger joints can be controlled by PossessedHand. In this paper, we discuss the results on the basis of the phases 1-4 discussed above. Thereafter, we propose interaction systems that can be realized by using PossessedHand.

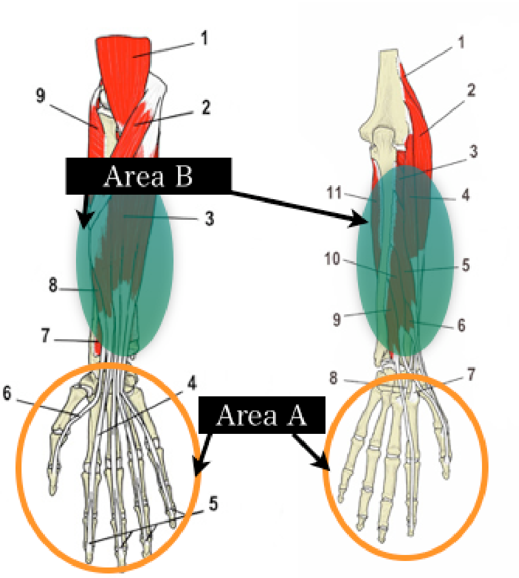

Figure 2: Area A:This area is involved in pinching, gripping, and holding motions. Area B: Electric stimuli are given in this area.

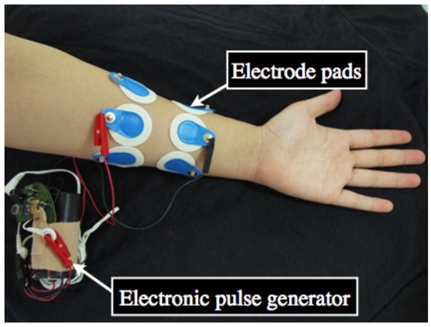

Figure 3: A prototype of PossessedHand (electronic pulse generator and electric pads).

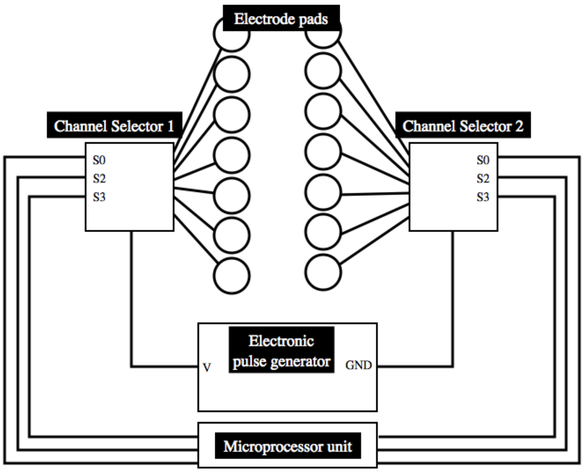

Figure 4: Configuration.

4. SYSTEM CONFIGURATION

4.1 Muscles and Stimulations for Making Hand Postures

We use EMS[2], in which muscle contraction is achieved by using electric impulses, to control a user's hand. The impulses are generated by PossessedHand and are transmitted through electrode pads placed on the skin to the muscles that are to be stimulated. PossessedHand with the desired output energy and compact size can be realized by using EMS[12].

An electrical stimulus of PossessedHand is applied to the muscles in the forearm of a user because many muscles that control the fingers and the wrist are located here. We adopt a forearm belt for PossessedHand. The electrical stimuli are generated by an electronic pulse generator and transmitted from 14 electrode pads. The pads are arranged on the upper and lower parts of the forearm of a user (Fig. 3); eight pads are needed to stimulate the muscles that are used to bend the joint in a finger, and six other pads are needed to stimulate finger extension and wrist flexion. PossessedHand stimulates seven muscles (superficial flexor muscle, deep flexor muscle, long flexor muscle of thumb, common digital extensor muscle, flexor carpi radialis muscle, long palmar muscle, and flexor carpi ulnaris muscle). These muscles are shown in area B in Figure 3. We can select a channel between a pad on the upper portion and one on the lower portion of the forearm. Thus, 7×7 channels are available.

4.2 A Prototype of PossessedHand

We built a prototype of PossessedHand using a pulse generator, a channel selector (Photo-MOS Relays Series AQV253), and 14 electrode pads (Fig. 3). The dimensions of PossessedHand are $10.0 \times 7.0 \times 8.0$ cm, and it is portable and suited for daily use. Its configuration is shown in Figure 4. Pulse width is 0.2 ms, and voltage is in the range 17-29 V.

5. EXPERIMENTS

We confirmed that PossessedHand can control the motion of 16 joints in the hand.

We conducted an experiment to confirm whether the finger joints can be appropriately moved to achieve desired hand postures. We selected an anode from the seven electrodes placed on the upper arm, and a ground electrode from the seven electrodes placed on the hand side. We tested 7-by-7 patterns of the electronic paths corresponding to each of three peak values of the pulse (17 V, 23 V, and 29 V); in other words, we performed 147 stimulations. We asked the subjects to eliminate strain in the hand.

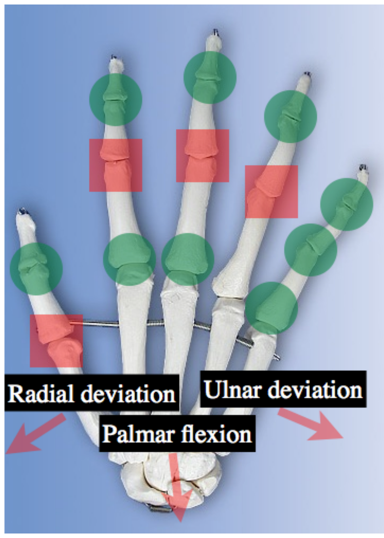

Figure 5: Operable joints. Arrows and squares indicate independently operable joints. Circles indicate ganed operable joints.

In the next section, we introduce 3 interaction systems of PossessedHand; navigation system, providing feedback for recognizing virtual objects, assistant system for musical performance. They correspond to phase 1 to 3 of the hand posture, respectively.

We have confirmed that PossessedHand can control seven independent and nine linked joints, i.e., a total of 16 joints. We have also confirmed that a clasped hand can be opened by stimulating a common digital extensor muscle. Further, we have confirmed that the users can recognize the motion of their hands motion even with closed eyes. Figure 5 shows the results of our experiment. These results suggest that PossessedHand can control hand postures in phases 1-3 as discussed above. In the next section, we introduce the three interaction systems of PossessedHand, namely, the navigation system, feedback system for recognizing virtual objects, and assistant system for musical performance. These systems correspond to phases 1-3 of the hand posture, respectively.

6. INTERACTION SYSTEMS OF POSSESSED-HAND

6.1 Navigation System(Using Phases 1, 2, and 3)

We propose a navigation system for PossessedHand (Fig. 1-b). PossessedHand can be used to make hand gestures to point to user's destination. This is advantageous because maps or announcements are not required when using Pos-

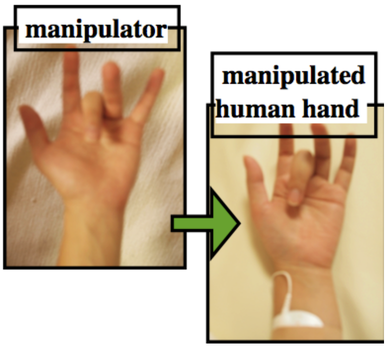

Figure 6: manipulator

sessedHand. Watanabe et al. proposed a navigation system in which galvanic vestibular stimulation (GVS) [15], [20], [3] is used. Since GVS affects user's sense of acceleration, user's walking direction can be controlled by the proposed system. However, this system cannot provide detailed information such as direction and distance. We propose a navigation system that controls wrist flexion and hand posture and provides detailed information about direction and distance.

6.2 Feedback System for Recognizing Virtual Objects(Using Phase 1)

PossessedHand can be used as a feedback system that conveys the existence of a 3D virtual object in the real world (Fig. 1-a). Haptic feedback is necessary for receiving information on virtual objects in augmented reality and mixed reality spaces. PossessedHand provides haptic feedback by controlling hand posture as well as visual feedback[4],[11] obtained using head-mounted displays or 3D displays.

6.3 Assistant System for Musical Performance (Using Phase 1, 2, and 3)

We propose an application of PossessedHand that helps a beginner learn how to play the musical instruments such as the piano and koto. In such musical instruments, subtle differences in tones are achieved by fine finger movements. The koto is a traditional Japanese stringed musical instrument. A koto player uses three finger picks (on the thumb, index finger, and middle finger) to pluck the strings. An appropriate hand posture is important for playing such instruments well (Fig. 6). PossessedHand can assist the beginner to acquire proper hand positions and postures. A hand-gesture recognition system with a camera[1] can also be used to identify whether the hand positions and postures are appropriate for the instrument. PossessedHand can help the beginner to learn professional techniques, which cannot be written in scores (Fig. 7). Furthermore, PossessedHand can help a distant learner learn to move fingers appropriately when playing musical instruments.

7. DISCUSSION

To extend the use of PossessedHand, we have to consider reaction rates, accuracy, and muscle fatigue[13] and realize automatic setup systems to control the voltage and the positions of the electrode pads. It takes 5 min for manually setting the position of the pads and voltage value. We have to develop an automatic setup system that is based on neural network systems, which provide rapid feedback on the position of the pads, voltage value, and joint angles. Thereafter, the use of PossessedHand can be extended for performing sports, learning finger languages, performing arts, and making handicrafts.

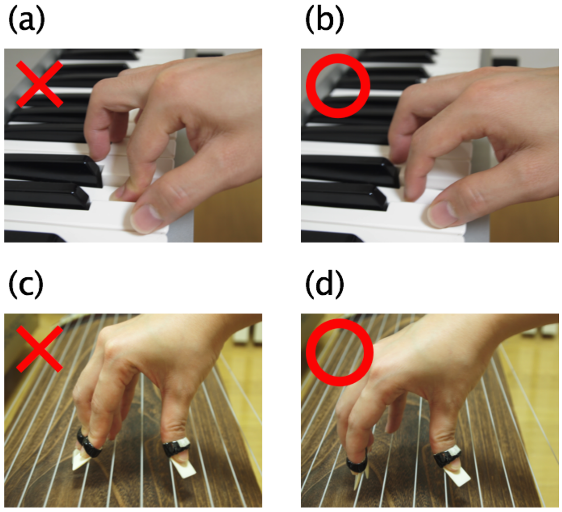

Figure 7: Hand postures for musical performances. (a)An incorrect posture for playing the piano. (b)A correct posture for playing the piano. (c)An incorrect posture for playing the koto. (d)A correct posture for playing the koto.

8. CONCLUSION

In this paper, we proposed the use of PossessedHand, a device used to control hand postures by an electrical stimulation technique. The electrical stimuli are transmitted from the 14 noninvasive electrode pads placed on the forearm muscles of the user; these stimuli control the motions of a user's hand. Our experiments confirmed that PossessedHand can to control the motion of 16 joints in the hand. The device can control the motion of seven independent joints and nine joints whose motions are linked with those of other joints. We confirmed that a clasped hand can be opened by stimulating the common digital extensor muscle. We also confirmed that the users can recognize the motion of their hand even with their eyes closed. On the basis of the results of the experiments, we proposed three interaction systems, namely, a navigation system, a feedback system for recognizing virtual objects, and an assistant system for aiding musical performance.

9. ACKNOWLEDGMENTS

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